Comparison of spectral radiance calibration techniques used for backscatter ultraviolet satellite instruments

M G Kowalewski[1,2] and S J Janz[2]
[1] Universities Space Research Association (USRA), Columbia, MD 21044, USA
[2] NASA Goddard Space Flight Center, Code 614, Greenbelt, MD 20771, USA

Introduction

BUV satellite instruments measure both earth radiance and solar irradiance in order to provide solar normalized radiances for trace gas retrieval algorithms. This method of normalization minimizes many instrumental calibration errors and is the reason why assessments of the pre-launch radiance and irradiance calibration uncertainties of the instrument are primarily concerned with how residual errors in the ratio between these two quantities will affect product performance. The ratio of the instrument radiance to irradiance sensitivity has historically been called the albedo calibration. Absolute and wavelength dependent albedo calibration errors become the primary source of errors in ozone retrievals from on-orbit data. The standard radiance calibration technique for BUV remote sensing instruments employs an external diffuser plate (e.g. Spectralon™) with a known bidirectional reflectance distribution function (BRDF) that is illuminated by a calibrated irradiance standard.

An alternative approach is to utilize a large aperture integrating sphere source. The Radiometric Calibration and Development Laboratory (RCDL) at NASA's Goddard Space Flight Center (GSFC) has provided a common radiometric calibration source for all major BUV satellite instruments for more than a decade in an effort to minimize calibration biases between multiple instruments that support long-term monitoring of ozone. The calibration source is a 50.8 cm internal diameter barium sulfate integrating sphere with a 20.3 cm diameter knife-edge exit port that is internally illuminated by four, 150 W QTH lamps.

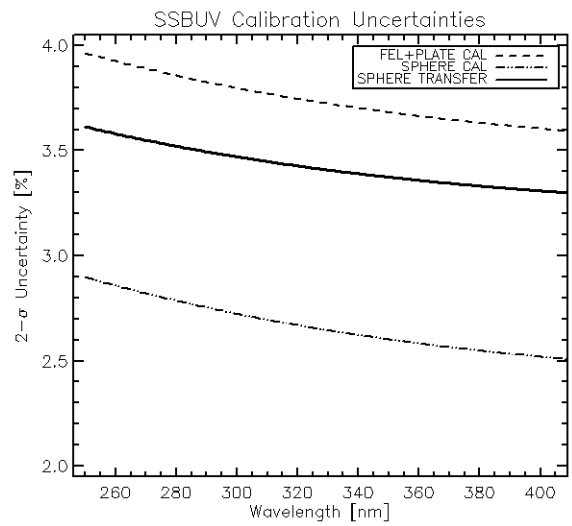
Calibration technique uncertainties

Uncertainties related to the flat plate diffuser calibration technique are primarily driven by the BRDF of the external diffuser and the absolute irradiance uncertainty of the source. RCDL diffuser panels are periodically calibrated in the NASA GSFC Diffuser Scatterometer Facility where past characterizations of diffuser plate BRDF have determined uncertainties of 1.5% [k=2] with wavelength dependent errors on the order of 0.5%. Uncertainties associated with the irradiance standard are reported by NIST for each lamp and are 1.75% at 250 nm for the RCDL lamps. An irradiance standard's horizontal and vertical illuminations differ due to the non-negligible vertical extent of the lamp filament structure. The extent of the lamp in the horizontal plane is small enough such that at a distance of 50 cm, the illumination can be treated as a point source; thus the intensity can be predicted to fall off by the inverse square of the distance from the diffuser panel center and $\cos\theta$, where θ is the incidence angle on the diffuser. The vertical illumination is more closely approximated by a $\cos^9\theta$ dependence although the exact shape is very lamp dependent. SSBUV is a non-imaging spectrometer and therefore spatially integrates the source over the full 10.4^o FOV requiring the differing horizontal and vertical illumination dependencies be taken

into account. The illumination correction over the SSBUV field of view at the external diffuser is in error by 1% [k=2] and is treated as a systematic uncertainty as it consistently under corrects for the lamp illumination. For this reason, it is recommended that hyper-spectral imagers orient the spatial axis of the instrument's input slit in the horizontal plane so as to minimize uncertainties related to illumination effects.

Propagating error terms results in a combined standard uncertainty [k=2] of 3.97% at 250 nm for this technique, which uses a single irradiance standard and a single external diffuser. For comparison, all external diffuser plate based calibrations in the RCDL utilize three irradiance standards and two calibrated external diffuser panels. Lamp restrike uncertainties are eliminated by carefully swapping between the external diffusers while the source is still illuminated. This results in a combined standard uncertainty of 2.89% [k=2] at 250 nm. It is highly recommended that multiple irradiance standards and external diffusers be used in order to minimize source related uncertainties as well as providing consistency checks between standards and diffuser panels.

The primary driver in the sphere calibration uncertainty is that of the sphere transfer calibration, which is reduced when multiple irradiance standards and transfer distances are used in the transfer. The following figure compares the combined uncertainties for the sphere calibration transfer, sphere radiometric calibration, and irradiance standard plus external diffuser calibration. These results show that the radiance of the sphere can be determined to better than 3% [k=2] in the UV and a full radiometric calibration of SSBUV using the sphere can be performed with better combined standard uncertainties to that of an irradiance and external diffuser based source. The uncertainties shown can be improved significantly in both methods through the use of multiple irradiance standards. In addition, the relative calibration of the standards can be determined by comparing the ratio of observed signal levels of the lamps to the ratio of irradiance standard calibrations.



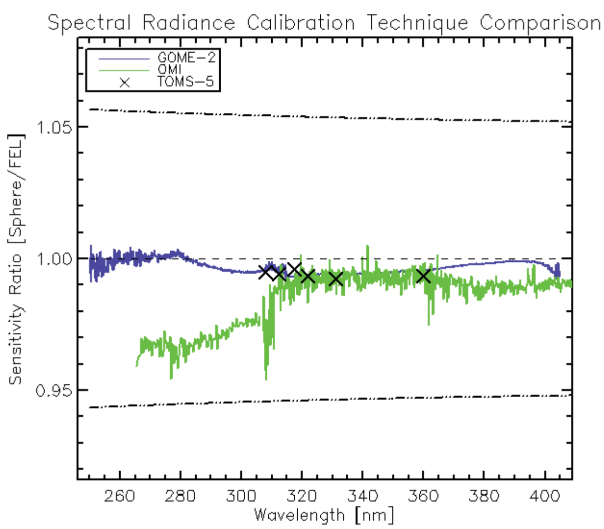
SSBUV 2-sigma uncertainties for the sphere radiance calibration (solid black), sphere irradiance transfer (dash-dot), and external diffuser and irradiance standard (dashed).

Satellite calibration comparisons

The NASA RCDL integrating sphere has been used in the radiometric calibration programs of many BUV flight programs. In this section, we present comparisons between the external diffuser and integrating sphere radiometric calibration techniques for the TOMS Flight Model 5 (FM-5), the Ozone Monitoring Instrument (OMI), and the Global Ozone Monitoring Experiment Flight Model 3 (GOME-2). For OMI and GOME-2, the calibration transfer of the integrating sphere was performed using an external diffuser plate, as described in the previous section, at multiple distances between the integrating sphere exit port and

external diffuser. The TOMS-FM5 calibration program did not include a sphere calibration transfer and relied on the sphere calibration transfer performed using SSBUV at NASA GSFC. Both the OMI and GOME-2 instruments were calibrated under thermal vacuum conditions while the TOMS FM-5 was calibrated at ambient temperature and pressure.

The following figure compares the instrument sensitivities for OMI, GOME-2 and TOMS-FM5 calculated from the integrating sphere calibration to those from the irradiance standard and external diffuser method.



Spectral radiance calibration comparison between sphere and external diffuser techniques for GOME-2 (blue), OMI (green), TOMS-FM5 (X's).

Both techniques agree for all three instruments to within the combined uncertainties

Conclusions

It has been shown that the integrating sphere and traditional external diffuser calibrations agree to within measurement uncertainties for multiple and varied flight instruments. The uncertainties associated with the external diffuser plate and irradiance standard, sphere calibration transfer, and direct sphere calibrations have been analyzed in detail to that a sphere based radiance calibration can achieve smaller combined standard uncertainties than the irradiance standard and external diffuser technique. The combined standard uncertainties represent the accuracies attainable for these calibration techniques using SSBUV and RCDL equipment and methods for single sources (i.e. external diffuser and irradiance standard combination).

The inherent characteristics of the integrating sphere offer definite advantages over the use of an illuminated diffuser when calibrating the spectral radiance sensitivity of radiometers. The primary advantage being that one does not need to know the BRDF (including associated uncertainties) of the external diffuser used to transfer the FEL irradiance to the sphere radiance. Other benefits include the ability to calibrate over a larger region of the instrument's FOV due to larger output area, and increased SNR and decreased test time due to higher signal levels. Eliminating the illuminated diffuser BRDF uncertainty results in a more accurate albedo calibration. It has also been shown that the accuracy of both calibration techniques is largely dependent on the uncertainty in the irradiance standard used. The use of multiple standard lamps and external diffuser plates significantly reduces the uncertainty for the traditional method as long as the vertical illumination of irradiance standard can be properly characterized and corrected. Use of multiple irradiance standards and transfer distances reduces the sphere-based calibration method uncertainty by nearly 1%.